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Conservation tillage and water availability for wheat in the dryland of central chile

N. Brunel [1,2*], O. Seguel [3], E. Acevedo[4]

*[1]Centro de Desarrollo para el Secano Interior, Universidad Católica del Maule, Talca, Chile. [2]Programa de Doctorado en Ciencias Silvoagropecuarias y Veterinarias, Universidad de Chile, Santiago, Chile. [3]Departamento de Ingeniería y Suelos, Facultad de Ciencias Agronómicas, Universidad de Chile, Santiago, Chile. [4]Laboratorio Suelo Agua Planta, Universidad de Chile, Santiago, Chile.*Corresponding author: nbrunel@ucm.cl*

Abstract

The dryland areas of Central Chile are associated to Mediterranean climate. Under these conditions, water availability during crop growth is a crucial factor for crop productivity. Conservation tillage systems play an important role in this area, increasing soil water availability; however, crop yield responses can be variable. Soil management should be aimed at reducing water loss and promoting water use by crops. The aim of this review is to analyze and discuss the factors affecting water availability in the Mediterranean drylands of Central Chile, as well as to study the effect of tillage systems on the water use efficiency of wheat.

Keywords: Mediterranean climate, water use efficiency, evapotranspiration, soil management

1. Introduction

Agricultural practices for the last 150 years are one of the main causes of environmental degradation of the Mediterranean regions, especially due to their negative impact on soil and water, producing a serious threat to human well-being (Zalidis *et al*., 2002). In Chile, the intensive tillage of the drylands has caused critical levels of erosion, physical degradation and low fertility levels of the soils, decreasing agricultural productivity.

The drylands of south-central Chile is a geographic area associated having Mediterranean climate, in which wheat is one of the main crops. Rainfall is the unique water supply for crops in this zone; the quantity and distribution of the rains make water the main limiting factor for production specially considering the high evaporation rate in the summer, which is characteristic of this climate (Austin, 1987; Turner and Asseng, 2005). The adaptation of the crop to this area depends on the water availability and its efficient use (Pala *et al*., 2007).

Soil management has an important effect on the availability and the water use efficiency of crops (Hatfield *et al*., 2001). However, the benefits of the soil management systems on the increase of wheat yields have been variable (Cantero-Martínez *et al*., 2007) The purpose of this review is to analyze and discuss the factors which influence the availability of water and the effect that tillage systems have in improving the efficiency of water use in wheat crops in the dryland zones of Central Chile.

2. Current Status

2.1. Conservation tillage in dryland zones

Wall (2006) defined conservation agriculture as "any management system that involves the following characteristics: a clear reduction in soil movement with the final objective of its complete elimination, except for the small movement involved in sowing; the preservation of a permanent or semi-permanent organic soil cover; and the rotation of economically viable crops".

From ancient times zero tillage and reduced tillage have been used by indigenous cultures; in recent years they have been adopted as efficient technologies for soil conservation in South American countries (Triplett and Dick, 2008). These tillage systems have also been proposed as an alternative to increase the water content of the soil, especially in zones in which the limitation of water availability exacerbates the degraded state of the soils.

Zero tillage, an integral concept which includes much more than the replacement of plowing by herbicides and direct seeding machinery, may be considered as one of the most representative models of sustainable agriculture; it is an agronomic practice which allows the cultivation of the soil with different production systems, maintaining and/or increasing its productive capacity, being the water availability and the soil physical, chemical and biological properties the keys to understand this result (Peterson *et al*., 1996; Acevedo and Silva, 2003).

2.2. Availability of water in dryland zones

The drylands of Chile, between 30º and 38º south latitude, are associated with the special condition of Mediterranean climate, which they share with four other regions of the world; southern Australia, southern California (USA), the extreme south of South Africa and the countries around the Mediterranean Sea. Wheat is one of the main crops grown in Mediterranean climate drylands (Schillinger *et al*., 2008). In Chile wheat is the base of the local agricultural economy; 60% of this crop is planted in drylands, covering an area of about 61,700 ha (INE, 2007).

Mediterranean zones are characterized principally by a concentration of precipitation in winter, with completely or nearly dry summers. Winter temperatures are mild and summers are warm to hot, with a high index of solar radiation (Cramb, 2000). In this climate, the rainfall pattern is one of the basic limiting factors for crop production, since about 70% of annual rainfall is concentrated in winter months, only 15% in spring and about 2% in summer; water is most available when the temperatures are less favorable for vegetative growth (Del Pozo and Ovalle, 1994).

Water is the main limiting factor for the wheat crop in the Mediterranean drylands of central Chile. The scarce availability of water during the critical developmental stages of the crop, coupled to the high evaporation rates in spring and summer, produce a water stress which affects its productivity (Turner and Asseng, 2005). The water use of the crop after the rainfall period is directly related to the quantity of water available in the soil (Lafond *et al.*, 1994); there are several factors which determine this water availability.

2.3. Available soil water at sowing

The stored water at sowing time may be an important complement to the seasonal rains in drylands, since this stored water may be more effective in promoting yield than the rainfall from sowing to harvest, (French and Schultz, 1984). Some authors have found a linear relation between yield and stored soil water at sowing (Musick *et al*., 1994; Asseng *et al*., 2001); however, Schillinger *et al*. (2008), in studies performed from 1953-1957 and 1993-2005, concluded that in terms of increasing productivity of wheat, spring rainfall was more effective than stored soil water at sowing. Considering that in drylands with Mediterranean climate less than 30% of annual rainfall occurs in spring, the rain which falls in this period is not enough to fulfill the water needs of this crop.

One technique used in dryland soils to improve water storage and nutrient availability at sowing is to leave the soil without a crop for a time, known as fallowing (Farahani *et al.*, 1998; Turner and Asseng, 2005). Leaving the land fallow may increase yield in dry areas due to an increase in water storage and in soil nitrogen at the time of sowing (Army *et al.*, 1959; Musick *et al*., 1994). Bonfil *et al.* (1999), from studies performed in Israel, concluded that under severe drought conditions (less than 150 mm annual rainfall), only a wheat-fallow system with zero tillage produces an acceptable grain yield. However, other authors have demonstrated low efficiency of fallowing for soil water storage, as well as adverse effects on soil quality and fertility (Stewart and Burnett, 1987; Stewart and Robinson, 1997). Farahani *et al*. (1998) estimated that in the great plains of the USA there was a 75% loss of the precipitation in the fallow period, with enhanced 16-25% efficiency of this practice in soil water storage with zero tillage. These authors suggested an improvement in the efficiency of use of precipitation by a decrease in fallow time and the incorporation of crop rotations adequate for dry zones.

The key to crop intensification, reducing or even eliminating fallow during crop rotation, is through zero tillage (McGee *et al*., 1997; Shaver *et al*., 2003). Other authors agree that in any system of crop rotation used in order to increase soil water content, whether fallow or continuous rotation, both must be adapted to systems of conservation tillage (Lafond *et al*., 1994; Bonfil *et al*., 1999).

2.4. Rainfall in the growing period

In dryland zones with Mediterranean climate, the increase in yield and productivity of agriculture depends upon a greater efficiency in the use of rainfall (Peterson *et al.*, 1996); the variability of precipitation during the growing period contributes to differences in yields (Cantero-Martínez *et al.*, 2007). Adequate water availability in the reproductive period, particularly from the beginning of spike growth until 10 days after anthesis, is necessary in order to achieve high grain yield (Acevedo *et al.*, 2002). Water deficit after anthesis produces early senescence and more mobility of assimilates stored pre-anthesis to grains in cereals (Zhang *et al*., 2008). Musick et al. (1994) emphasized the importance of the period of stem elongation to anthesis, continuing in early grain filling, to maintain potential production in dryland zones. Considering that water use in the interval from the beginning of spike growth to anthesis determines the number of grains, a variable which is closely related to wheat yield,it is evident that a stress in this period will reduce grain yield (Cayci *et al*., 2008; Olivieri, 2008).

In Australia, Cornish (1950) associated 65% of the variation in wheat production with the variability of rainfall from April to October; rain in winter months was more effective in producing high yield. Seif and Pederson (1978) reported that in central Australia precipitation in spring, from three weeks before to two weeks after anthesis, explained 86% of the variation in yield.

2.5. Water stored at depth

In rainfed crops, water stored at depth in the soil is valuable during the most sensitive stages to water deficit (Passioura, 1983). The absorption of water depends to a great extent on the extension and depth of the root system (Kirkegaard and Lilley, 2007), thus the early development of an extensive root system that can use the water from the deeper soil strata at the end of the growth period is particularly important in periods of drought (Hurd, 1964; Bonfil *et al.*, 1999), as long as there is water at depth.

Kirkegaard *et al.* (2007) demonstrated that small amounts of water in the subsoil may be very valuable for grain yield, concluding that when there is moderate stress after anthesis, 10.5 mm of additional water in the subsoil in the strata from 1.35-1.85 m depth, increased grain yield by 0.62 t ha^{-1}, indicating an efficiency of 59 kg of grain ha^{-1} mm^{-1}.

Wheat roots are mostly found between 0 and 120 cm depth (Bonfil *et al*., 1999), but they can reach from 150 cm (Cramb, 2000) to more than 240 cm (Winter and Musick, 1993) at anthesis (time at which wheat roots reach maximum depth). In southern Australia, wheat root depth varied from 80 to 180 cm in 36 fields evaluated; the main differences in root depth were explained by the type of soil, incomplete wetting of the soil profile, and the length of the vegetative period (Kirkegaard and Lilley, 2007). Root growth is less affected than vegetative growth under conditions of water stress (Klepper, 1992); there is a general consensus that wheat root growth reaches its maximum at anthesis (Valle, 2004; Kirkegaard and Lilley, 2007), and then decreases substantially (Gregory *et al.*, 1978). In Th rainfall in Mediterranean environments exceeds evapotranspiration only at the end of tillering; from tillering to maturity the crop depends on the storage of water in the subsoil (French and Schultz, 1984). For this reason, the capacity of the soil to store water is even more relevant in years with early rainfall when the crop depends mainly on stored water (Asseng *et al*., 2001; Olivieri, 2008; Lawes *et al.*, 2009).

2.6. Runoff, percolation and evaporation of water from the soil surface.

Studies in dryland areas usually consider surface runoff and deep percolation as negligible (Angus and van Herwaarden, 2001; Cantero-Martínez *et al*., 2007; Cayci *et al*., 2008), which may lead to an overestimation of evapotranspiration and underestimation of water use efficiency (WUE), especially in humid seasons (Sadras and Angus, 2006).

In the rolling Mediterranean drylands of central Chile runoff is a substantial factor of water loss; it is highly dependent on the soil properties, slope and variability and intensity of the annual rainfall. In a study by Uribe *et al.* (2003) in degraded soils of Chilean drylands, the runoff coefficient was greater than 50% in soils which had lost a large part of their capacity for water infiltration and water retention; these authors reported that the rain which fell in the months of March and April was stored in the soil, while the rain after that period produced surface runoff. A study performed in the drylands close to Ninhue (VIII Region of Chile) showed that runoff varied from 10% in dry years to more than 50% in wet years; for a year with low precipitation (400 mm), the runoff measured in small watersheds was approximately 40 mm (Uribe *et al*., 2004).

The high clay content of these dryland soils governs the water flow in the profile. A study by Quezada and Fernandez (1977) in an Alfisol showed that this type of soil had very slow water movement in the profile. The results indicated that at field capacity, the non-saturated hydraulic conductivity was less than $3.2*10^{-4}$ cm day^{-1}; the authors associated this low flux with the fact that about 60% of the soil pores had a diameter lower than 0.20 microns.

Evaporation from the soil is one of the main causes for water loss in dryland areas, mainly in the first periods of high temperature when the crop is at the initial phenological stages, with low soil coverage. Both, surface runoff and evaporation from the soil coincide with the period when the soil surface is not completely covered by the crop. Thus in wet years these factors may result in significant loss of rain, drastically affecting the availability of water. Stewart and Burnett (1987) indicated that in a wheat rotation in dryland zones of the USA, the loss of rainfall by evaporation during the period without crops varied from 36% for the system of continuous rotation to 61% for a wheat-fallow system. As is the case with deep percolation,evaporation from the soil surface is also complex to measure in the field; thus usually the concept of evapotranspiration is used, which includes the components of evaporation from the soil and transpiration by the crop (Sinclair *et al.,* 1984; Hatfield *et al.,* 2001).

2.7. Water use by the crop

Water consumption in crop production is normally measured in terms of evapotranspiration (Cantero-Martínez *et al.*, 2007; Katerji *et al.*, 2008; Zhang *et al.*, 2008) and water use efficiency (WUE), since 99% of the water used by the crops is released to the atmosphere as water vapor (Katerji *et al.*, 2008). The relation between yield and the amount of water evapotranspired by the crop is generally linear (French and Schultz, 1984; Sinclair *et al.*, 1984; Musick *et al.*, 1994). A first analytical approximation of the relation between yield and water use was suggested by De Wit (1958) through the equation:

$$Y = m*T/E_o \qquad (1)$$

Where Y is biomass yield, m is a constant, T is the total transpiration during the growing season and Eo is the mean seasonal evaporation from a free water surface. Later, Bierhuizen and Slatyer (1965), considering that the processes of biomass production and transpiration depend on concentration gradients and resistance to diffusion, proposed a variant to equation (1) which incorporated the concept of atmospheric vapor pressure deficit:

$$Y = T^{*}k^{*}(e_s - e_a) \qquad (2)$$

where k is a constant and the difference in the saturation vapor pressure at the atmospheric temperature (e_s) and the real vapor pressure at field conditions (e_a) is the atmospheric vapor pressure deficit.

Graphs of experimental data for different species show the linear relation between yield and total crop evapotranspiration. Using a mathematical model that considered the different concepts involved in this relation, Sinclair *et al.* (1984) showed that the slope of the linear regression estimates the use efficiency of transpired water and that the intercept in the evapotranspiration axis estimates direct evaporation from the soil. French and Schultz (1984) used this model to determine that in the Southern Hemisphere the water use is closely related to the rain from April to October, and if there is a negligible runoff, the rainfall in this period may be used to approximate the water use of the crop. These authors developed the concept of potential yield under limiting water for wheat, using data collected over 12 years in 61 sites in southern Australia (Figure 1). They estimated that for crops with high yield and efficient water use the direct evaporation from the soil was 110 mm, about a third of the total water use. The quantity of water transpired by the crop which contributes to a grain yield potential is close to 20 kg ha^{-1} mm^{-1}.

The relation between yield and water use is a simple method to divide the water used into its components of transpiration and soil evaporation, and has been used in dryland zones with Mediterranean climate. French and Schultz (1984) concluded that low rainfall by itself does not explain the low yield of many crops, since the points below the dashed line in Figure 1 indicate sites where production was limited by factors such as extreme temperatures, agronomic deficiencies, effects of pests and diseases, and possibly soil erosion. Several authors coincide that water use and transpiration in the reproductive state is crucial to obtain high yields in WUE (Musick *et al.*, 1994; Oweis *et al.*, 2000; Katerji *et al.*, 2008; Blum, 2009).

2.8. WUE of crops

In regions where the water is a limiting resource, the need to produce the maximum yield using efficiently the available water is a key factor in agricultural productivity (Cantero-Martínez *et al.*, 2007; Zhang *et al.*, 2008). Due to the low WUE that the productive systems of dryland areas have (Zwart, 2004), this topic has received considerable attention.

WUE has been used as an indicator of the impact of crop management in dryland systems, it is closely related to the effectiveness of the use of rainfall, since rain is the only source of water (Hatfield *et al.*, 2001).

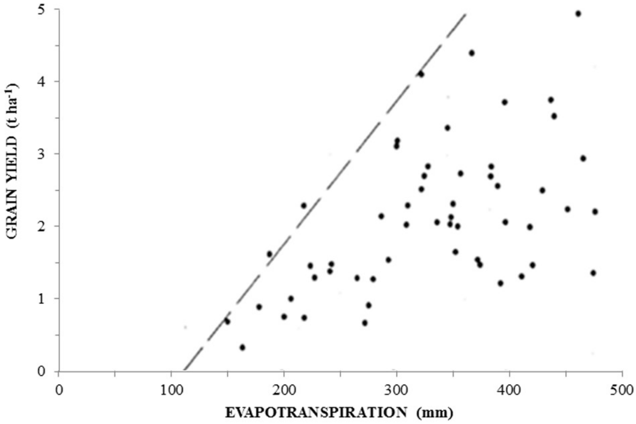

Figure 1. Wheat yield potential for southern Australia. From French and Schultz (1984).

This concept may be formulated using several different scales of processes and time, such as the relation between biomass accumulation (expressed as CO_2 assimilation, total crop biomass or grain yield) and water consumption (expressed as transpiration, evapotranspiration or total entrance of water into the system) (Sinclair *et al.*, 1984). From the agronomic perspective, the most used relation is:

$$WUE = Yield\ (kg\ ha^{-1}) / Water\ use\ (mm) \qquad (3)$$

It may be deduced from this simple equation that a for a constant WUE, a greater amount of water available for use by the crop will increase the final yield, which in drylands will depend on techniques to achieve a higher efficiency in the use of precipitation (Peterson *et al.*, 1996; Hatfield *et al.*, 2001).

Gregory (1991) developed a more explicit form of equation (3), using the rainfall in the growth period as an approximation of the evapotranspiration, and assuming that the transpiration rate was proportional to the deficit in atmospheric vapor pressure (Sinclair *et al.*, 1984), giving:

$$WUE = k / ((1+E_s/T)*(VPD)) \qquad (4)$$

where k is a crop-specific coefficient, Es is the water loss from the soil surface due to evaporation, T is the crop transpiration and VPD is the mean seasonal atmospheric water pressure deficit. Analysis of equation (4) indicates important ways to improve WUE, using agronomic management to reduce the relation (Es/T) and taking into consideration the marked seasonal variation in water pressure deficit in Mediterranean climates (Acevedo *et al.*, 1991) by growing crops in the period of lower VPD. Thus, management practices which reduce the incidense of solar radiation to the soil surface and increase water availability, reducing loss by evaporation from the soil, would have a positive impact on WUE (Acevedo *et al.*, 1991; Musick *et al.*, 1994; Hatfield *et al.*, 2001).

2.9. Conservation tillage and soil water availability

The results of a number of investigations show that conservation systems generally maintain more water in the soil than the conventional systems, which is explained by the effect of the crop residue left on the soil surface, producing less evaporation, an increase in organic matter and an improvement of the physical properties of the soil (Unger, 1994; Shaver *et al.*, 2003; Valle, 2004). However, the availability of water in the soil profile may be variable for each tillage system (Lafond *et al*., 1994).

Negi *et al*. (1981) reported for plots with zero tillage twice as much water available to the plants at a depth of 30 cm than in plots with conventional tillage, while Tollner *et al.* (1984) found that the soil with zero tillage had significantly less water available for the plant near the soil surface than conventional tillage. In a review of research in northern China, the results showed that conservation tillage increased water storage from 3% to 50% and crop yield increased from 2-36% compared to conventional tillage, along with reducing the effects of erosion (Wang *et al.*, 2007); in dry years the effect of conservation tillage tended to be greater than in wet years compared with conventional tillage. Alvarez and Steinbach (2009) found that for 35 trials in the Pampas region of Argentina there were small differences in the water content between tillage systems when the soils were humid; the differences increased in drier soils; zero tillage had a mean of 13-14% more water than tilled soils. However, the authors found that wheat yields were significantly greater with conventional tillage than in systems with reduced tillage.

The effect of the protective mantle of organic residues, improving the infiltration of water into the soil and reducing water loss by direct evaporation, is a key factor in dryland zones, in which the high levels of solar radiation and slow infiltration of water into the soil increase the loss of water and reduce its availability for the plant. The results of Fuentes *et al*. (2009) in an area of Mexico with mean precipitation of 600 mm year^{-1} showed that treatments with zero tillage and stubble on top of the soil had a greater water content and lower penetration resistance than the same treatment without stubble. In dryland conditions with annual precipitation greater than 250 mm, zero tillage increased yield and WUE (Aase and Pikul, 1995; Jones and Popham, 1997).

2.10. Conservation tillage and soil physical properties

The cover of stubble left on soils managed with conservation tillage systems favors not only the increase in the water available for plants due to the decrease of water loss by evaporation (Fuentes *et al*., 2009), but also has effects on the physical properties of the soil, specially in the top few centimeters (Martinez *et al.*, 2008). Blanco-Canqui and Lal (2007) observed that the top three centimeters of soil under treatments with stubble were rich in decomposing organic material and were more porous, as well as having a significantly higher worm population compared to plots without stubble. This organic material increases the microfauna and microflora of the soil, as was observed by Acevedo and Silva (2003), who measured an increase of 30-40% in the microbial population of soils with zero tillage.

Ela *et al* (1992) reported an increase in water flow in the soil due to the development of macropores constructed by worms. However, an increase in the worm population does not always increase the rate of water infiltration in soils, since these organisms may produce unconnected channels which do not necessarily favor the water movement into the soil profile (Blanco-Canqui and Lal, 2007).

Some authors have found that conservation tillage may reduce the total porosity in the surface horizon of the soil, modifying the pore size distribution, with predominance of fine pores, while the effect of plowing in a conventional system increases the number of larger pores (Negi *et al*., 1981; Tollner *et al*., 1984; Hill *et al.*, 1985). The more compact surface of soils with zero tillage would explain the decreased infiltration of water in the profile (Pelegrin *et al*., 1990; Martinez *et al.*, 2008). Nevertheless, Dexter *et al*. 2004) found a lower hydraulic conductivity of the plough layer in a conventional system attributed to the destruction of biopores by tillage. The increase in organic carbon observed in soils with conservation tillage may increase the proportion of macropores and lead to higher infiltration rates than with conventional tillage

(Alvarez and Steinbach, 2009; Fuentes *et al.*, 2009; Stone and Schlegel, 2010). This apparent contradiction is generally explained by the susceptibility of soils to compaction. The infiltration of water and the saturated hydraulic conductivity, which control the partition of rainwater and the magnitude of surface runoff, are also sensitive indicators of soil structure (Blanco-Canqui and Lal, 2007) and of the impact of tillage systems on soil.

Alvarez and Steinbach (2009) found that the structure of the soil with conventional tillage evaluated by the change of mean weigh diameter of the aggregates was on average 70% more unstable than for soils with conservation tillage.. This result agrees with those of other authors, who conclude that the stability of aggregates is affected by the tillage system; treatments with zero tillage with stubble have a higher mean diameter of aggregates (Cannell and Hawes, 1994; Martinez *et al.*, 2008; Fuentes *et al.*, 2009); which may be attributed to a greater content of organic material in the soils with zero tillage (Martinez *et al.*, 2008). Six *et al.* (1999) found that total C was 9% to 16% lower in soils with conventional tillage compared to zero tillage, being the main differences in the first 5 cm of soil. Tillage practices also affect the amount, size and distribution pattern of roots, altering the physical properties of soils, such as pore size, bulk density and soil strength (Chan and Mead, 1992).

In the upper 15 cm of soil, improvement in water retention capacity and soil structure result in higher root growth of wheat under zero tillage (Acharya and Sharma, 1994; Merrill *et al.*, 1996; Lampurlanés and Cantero-Martínez, 2003; Valle, 2004). However, it has been reported compaction of clayey soils under zero tillage, negatively affecting the growth of deep roots and water absorption from the deeper horizons of the soil profile (Alvarez and Steinbach, 2009). The increase of bulk density may be attributed to a natural consolidation of soil and the compaction due to the movement of agricultural machinery (Pelegrin *et al.*, 1990), the latter by the action of the force transmitted to the soil by the wheels of tractors and sowing machines (Acevedo and Silva, 2003; Schjonning *et al.*, 2006). Jin *et al*. (2007) reported that the treatment with zero tillage reached higher values of bulk density; a mean of 1.41 g cm^{-3} compared to the 1.26 g cm^{-3} of conventional tillage.

The technique of subsoiling as a complement to zero tillage minimizes the effect of compacting by rupturing the compacted layers, allowing the accumulation of a water reserve below the surface horizons, increasing the depth of rooting and improving water availability for plants, which considerably improves their resistance to periods of drought (Raper *et al.*, 1998; Hong-ling *et al.*, 2008). Subsoiling promotes higher water storage in the deeper horizons of the soil profile, principally in dry seasons, which would improve yield in dryland areas and increase the WUE of the crop (Pikul and Aase, 1999; Jin *et al.*, 2007; Mohanty *et al.*, 2007; Hong-ling *et al.*, 2008). Aldea *et al*. (2005), who used a chisel plow before sowing, found that this technique may provide transitory benefits in soil managed with zero tillage, with significant differences in infiltration at planting when compared to the treatment without using the chisel plow; however, no differences were found at the flowering and harvest stages. Wang *et al*. (2007) found that the subsoiling technique, as a complement to zero tillage, produced an increase of 18.8% in wheat yield and 16.8% in WUE compared to conventional tillage. Similar results were found for oats by Hong-ling *et al*. (2008), who reported that subsoiling increased water storage in the soil between 0 and 100 cm depth, which in dry periods allowed a higher amount of water from the deeper soil, producing a higher WUE.

3. Discussion

In dryland zones with Mediterranean climate, the distribution pattern of rainfall, especially in soils with low water storage capacity, notably affects water availability, and may be more important than the total amount of rainfall in determining crop yield (Tanaka and Anderson, 1997; Olivieri, 2008; Stone and Schlegel, 2010). The water deficit of plants during the period of reproduction and grain filling, mainly due to an unfavorable rainfall regime, is the most limiting factor for wheat production in these zones.

In the Mediterranean dryland of Chile, an average rainfall of 700 mm year^{-1}, as occurs in the Cauquenes area, should provide adequate availability of soil water during the growth period of the crop, with a positive impact on final yield. However, the real crop productivity is low and does not fulfill this expectation. Figure 2 shows the mean monthly rainfall for Cauquenes.

Figure 2 shows that the water available at sowing depends mainly on the rainfall during May, which can be scarce; thus the practice of summer fallowing, which is usually used by the farmers in the area, is insufficient for water storage, since summer precipitation is practically inexistent. On the other hand, only 15% of total annual precipitation occurs during the period of spike growth. Any practice which favors the water storage in the soil will favor the water availability for crops during the high water demand period.

The degraded state of the soils as a result of cereal cropping with intensive tillage for many years in the dryland zone of the Coast Range in Chile has reduced the water retention capacity of the soil. The low capacity of water infiltration and retention of the soils of this area (Uribe *et al*., 2003) increases water loss, due to surface runoff and evaporation. Figure 3 illustrates the magnitude of the main events affecting water availability in the zone. The amount of precipitation decreases drastically during the period of maturation, coinciding with the greatest water demand of the crop; runoff is closely related to the intensity of the rainfall, resulting in high water loss during winter months.

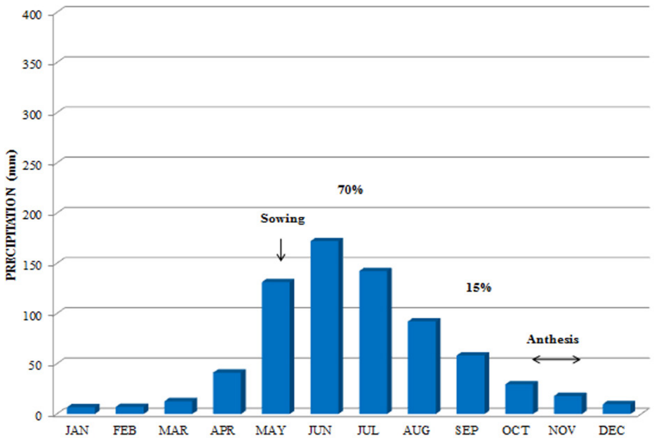

Figure 2. mean monthly precipitation in Cauquenes, Chile (1958-2009). Source: Instituto de Investigaciones Agropecuarias, Centro Experimental Cauquenes.

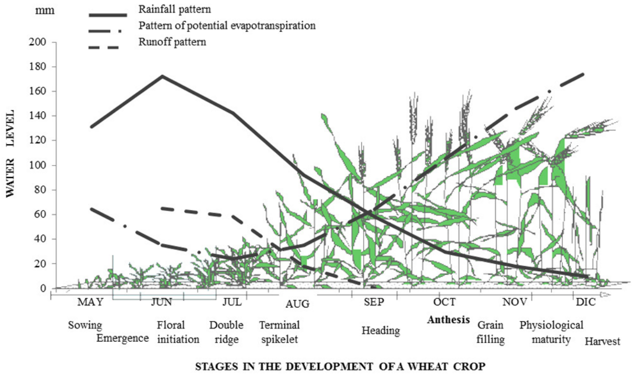

Figure 3. Diagram of the patterns of precipitation, potential evapotranspiration and superficial runoff during the development of wheat in Cauquenes, Chile.

Figure 3 clearly shows that the water deficit begins in September, and until the end of the growth period the evapotranspiration demand is greater than the rainfall. In this period the ability of the soil to retain available water and to allow roots to reach the deepest horizons of the soil profile play a fundamental role in the normal development of the crop.

The activity of deep roots helps to reduce water loss from deep percolation, even in clayey soils, where the deep drainage is much less important than direct loss by evaporation from the soil (Passioura, 2006). The dryland soils in south-central Chile are found in the hillsides of the Coastal Range; showing variable degrees of degradation. In this zone, information about the effective rooting of wheat is not available; however, rooting depth is restricted by dense clay in the subsoil, with high values of bulk density (1.4-1.5 g cm^{-3}) which increases at depth (CIREN, 1997). These conditions produce a dominance of fine pores, with good water retention but poor aeration, which limits the penetration of roots.

The optimum development of wheat depends on a number of agronomic practices focused on the increase of soil water storage and the improvement of WUE of the rain which falls during winter, generating a higher availability of water in the most critical months for crop development, in which the water stored in depth is extremely useful for crops (Passioura, 1983). Although in terms of water use there are no clear advantages of conservation tillage systems, these provide a good alternative to increase available water in the soil (Hill *et al*., 1985; Jin *et al*., 2007; Alvarez and Steinbach, 2009; Fuentes *et al*., 2009), especially in dry years, in which the increase in yield is determined by the WUE and may suggest changes in the pattern of water use before and after anthesis (Cantero-Martínez *et al*., 2007).

The increase in organic matter content and the reduction of the perturbation of the upper soil due to conservation tillage systems improve the physical, chemical and biological properties of the profile, improving soil structure and water retention capacity. The climate of the dryland zone of the Coast Range of central Chile has a strong impact on soil water balance during the period of crop growth; in this scenario, conservation tillage has great benefits. Covering the soil with stubble protects the soil from the direct impact of raindrops, which minimizes the disaggregation of particles and maintains the soil structure, favoring water infiltration and reducing surface runoff, as well as acting as an isolation of the soil from direct solar radiation, reducing heat flow and decreasing water evaporation from the soil surface. Complementary management such as subsoiling contributes to increase the potential productivity of systems which have been degraded by decreasing soil compaction, thus studies should be continued which integrate the dynamics of tillage-erosion with water use and plant production.

4. Conclusions

From the analysis of soil water availability during the period of crop development in the dryland zones of south-central Chile, we conclude that the main mechanisms of soil management practices should be oriented to increase the infiltration and storage of water in the soil profile, reducing water loss from the soil by evaporation and favoring the development of a deep root system which will a produce more efficient use of water.

Systems of conservation tillage have clear benefits for wheat productivity, due both to the protective cover of stubble and the improvement of the structural conditions of the soil; both tend to favor the capacity of water storage in the soil profile. The particular climatic conditions of the Mediterranean drylands of the Coast Range of central Chile and the current degradation of its soils require that these effects be quantified.

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